(2)

Report No. CG-D-06-89

INVESTIGATION OF THE VALIDITY OF EXISTING STANDARDS CONCERNING THE USE OF GLASS WINDOWS ON SHIPS

Thomas J. Ingram
Philip M. Greenwald
Henry E. Hagy

ABS Worldwide Technical Services, Inc.
Government Services Unit
45 Eisenhower Drive
Paramus, NJ 07653-0910

FINAL REPORT
AUGUST 1988

This document is available to the U.S. public through the
National Technical Information Service
Springfield, Virginia 22161

Prepared for:

U.S. Coast Guard
Research and Development Center
Avery Point
Groton, Connecticut 06340-6096

and

U.S. Department Of Transportation
United States Coast Guard
Office of Engineering and Development
Washington, DC 20593-0001

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The contents of this report reflect the views of the Coast Guard Research and Development Center, which is responsible for the facts and accuracy of data presented. This report does not constitute a standard, specification, or regulation.

SAMUEL F. POWEL, III
Technical Director
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340-6096

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-06-89		

4. Title and Subtitle
INVESTIGATION OF THE VALIDITY OF EXISTING STANDARDS CONCERNING THE USE OF GLASS WINDOWS ON SHIPS

5. Report Date
AUGUST 1988

6. Performing Organization Code

7. Author(s)
T.J. Ingram, P.M. Greenwald, and H.E. Hagy

8. Performing Organization Report No.
CG R&DC 17/88

9. Performing Organization Name and Address
American Bureau of Shipping
Government Services Unit
45 Eisenhower Drive
Paramus, New Jersey 07653-0910

10. Work Unit No. (TRAIS)
GSBU-36-R1

11. Contract or Grant No.
DTCG39-88-C-80616

12. Sponsoring Agency Name and Address
U.S. Coast Guard Research and Development Center
Avery Point
Groton, Connecticut 06340-6096

Department of Transportation
U.S. Coast Guard
Office of Engineering and Development
Washington, D.C. 20593-0001

13. Type of Report and Period Covered
FINAL --
February to August 1988

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This document summarizes the compilation and evaluation of existing international standards for the design of marine windows. In addition, general industrial and architectural design standards were investigated and related literature reviewed for information which might be applicable for use in the design of the large windows.

A technical analysis was performed to determine the basis for the design criteria in the existing standards and an evaluation made on the compatibility of this data with current glass industry design practice. Reviewed the appropriateness of testing and quality assurance requirements.

Provided recommendations regarding the strength of glass windows and recommended test procedures.

17. Key Words
Glass, Window, Wind Load, Wave Load, Superstructure, Deckhouse

18. Distribution Statement
Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

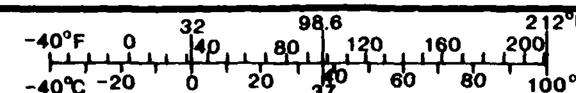

TABLE OF CONTENTS

[BLANK]

INTRODUCTION

The Coast Guard is the federal agency which holds statutory responsibility for ensuring the safety of U.S. flag vessels. This responsibility is met through plan review, inspection during construction, periodic in-service inspections, and casualty investigations.

The design of the steel hull structure of standard configuration vessels is well understood and documented. As a result, hull structural failures caused by wind and wave forces are quite rare. The ability of glass to withstand these forces is not so well understood; as a result, windows on ships have traditionally been small, thick portholes mounted high on the superstructure. Recently, there has been a trend for designers to want to put larger and thinner windows in more locations on ships. This is especially true on small passenger vessels which are used for excursions and dinner cruises. In order to technically evaluate these proposals, standard criteria is required. While some standards exist or are in the proposal stage, the validity and range of their applicability to large window construction are unknown.

ABSTECH, was tasked by the U.S. Coast Guard Research and Development Center to investigate the validity of existing or proposed standards concerning the use of glass windows on ships and the limits of applicability. In addition, documentation on research in the area of glass strength and its degradation over time due to exposure to the elements was investigated.

The structural adequacy of a window depends on the absolute magnitude and duration of the load applied to the window and on the ability of a window to resist this loading. In this study, the resistance or strength aspects of glass windows were initially addressed. Consideration was also given to the changes which occur to glass over time due to mechanical cycling, thermal cycling, and chemical exposure typically found in the marine environment.

Since the development of all standards involve some level of technical judgement, proposed changes to the standards or a new testing framework should be developed to improve the validity of the approach used for the evaluation and approval of glass windows in ships.

In order to accomplish this work, the efforts for this study were divided into several phases or tasks.

The initial phase of the work (Task 1) consisted of the compilation and evaluation of existing and proposed design standards for marine windows. As part of the evaluation made for these documents, technical information was collected to permit a comparison of the approaches taken for a number of specific items of concern, including:

1. Type and size of vessels for which the standard is applicable.

2. Types of glass to which the standard is applicable.

3. Testing procedures used to determine the design criteria.

4. Method used to correct for degradation of glass properties over time, if any.

General industrial and architectural design standards were also investigated to determine current strength standards for large windows in buildings and for factors of safety used for the determination of wind load and impact loads.

A compilation was also made of research documentation and publications containing information concerning the degradation over time (if any) of glass suitable for marine use caused by mechanical cycling, thermal cyclings (-10 to 80 degrees C), chemical exposure to the marine environment, exposure to ultraviolet light, and any available data on accelerated life testing of glass.

Based upon the information obtained from the review of existing standards, the second phase (Task 2) consisted of an investigation of ASTM glass standards and U.S. glass manufacturers' literature to compare material and testing specifications commonly available in the U.S. with those required by international marine window standards. Additionally, the maximum pressure loadings and tensile stresses permitted by the marine standards were compared with U.S. industry standards for permitted pressure loadings.

After completion of Tasks 1 and 2, proposed changes to the existing marine standards were developed to incorporate the information obtained from the previous research into an outline which may be used to update design standards for marine glass windows for U.S. flag vessels by the U.S. Coast Guard.

The research team specifically reviewed wave loading criteria to determine if the methods used as a basis for current standards yields a glass thickness capable of resisting an equivalent wave pressure. Comparisons to deckhouse structure loading and side shell plating loading were made to determine the equivalent loading. Analytical methods of determining the wave loading pressures from breaking and non-breaking waves and consideration of possible testing methods including accelerated testing and direct strain gauge measurements were reviewed.

In considering the trend toward larger windows, the existing standards were specifically reviewed and evaluated to determine their applicability for the design of windows significantly larger than the "standard" sizes normally used on ships.

As a final area of investigation, the properties of glass types other than the tempered glass currently required by existing standards were investigated for possible marine applications.

REVIEW OF EXISTING STANDARDS

Pertinent existing standards for the design of glass windows on vessels were compiled and reviewed. This effort included a number of standards issued by international organizations involved with the design and construction of marine vessels:

International Standards Organization	(ISO)
British Standards Institution	(BSI)
Swedish Shipbuilding Commission	(SIS)
Norwegian Industrial Standards Organization	(NVS)
Japanese Industrial Standards	(JIS)
Registro Italiano	(RINA)

General industrial and architectural standards were also included in this investigation to determine the methods currently utilized to estimate window loads and the maximum allowable loads or stresses permitted for the various grades of glass.

The results of this research are summarized in the following pages and are organized by direct applicability to shipboard installations and issuing organization.

1. Marine Window Standards

A. International Standards Organization (ISO)

ISO 614 - "Toughened Safety Glass Panes for Ships' Side Scuttles and Ships' Rectangular Windows--Punch Method of Non-Destructive Strength Testing".

This standard specified a method for the non-destructive strength testing of toughened safety glass panes for ships' side scuttles and windows complying with ISO 1095 and 3254.

Each panel to be tested is subjected to a point load test increasing from zero up to the rated proof load at a rate of 1000 Newtons per second and is to "remain unbroken and ... show no signs of damage". No criteria is provided for determining what constitutes "damage" and how it is to be measured. Proof load is established solely on glass thickness.

ISO 1095 - "Toughened Safety Glass Panes for Ships' Side Scuttles"

This document establishes standard sizes for scuttles and provides requirements for production tolerance, testing (per ISO 614) and marking of panes.

Table 6 provides the maximum pressure load for standard-size clear scuttles. For obscured panes installed with the obscured surface inwards, a reduction in maximum pressure load of 45% is specified. This requirement is based on the fact that obscuring is accomplished by acid etching or sandblasting, which create surface flaws on the inward side of a window.

ISO 3254 - "Toughened Safety Glass Panes for Ships' Rectangular Windows".

This standard gives the same definitions and specifications as ISO 1095 for clear and obscured toughened safety glass panes for ships' rectangular windows.

The maximum pressure heads to which standard-size, clear toughened safety glass panes glazed on all four edges shall be subjected, are given in Table 6 of the document. Where one or both dimensions of a wheelhouse window are different from those given in this table, the maximum allowable pressure shall be determined using the formula given in the Annex to the document. The formula considers the nominal thickness of the glass pane, the window size ratio factor, and the minor dimension of the window.

While the Annex is specifically intended for design of windows for wheelhouses, the method is equally applicable to other areas of the superstructure. It appears that at the time of the writing of this specification, standard ISO window sizes would be required everywhere except in the wheelhouse. Apparently, this standard did not foresee a trend toward much larger glass areas.

No requirements or procedure are provided for determining the allowable head at any level. The pressure head for the design of a window is to be the same as applied to the particular deckhouse structure, based on the requirements of the Classification Society.

ISO 3903 - "Ships' Ordinary Rectangular Windows".

This document provides general guidelines for windows on ships. Extensive material is included on technical requirements for the frames of various opening and fixed frames.

Establishes heavy (Type E) and light (Type F) windows, the major difference between the types "E" and "F" being the thickness of the glass pane and the tensile strength and elongation of the material for the main components including the main frame, glass holder, retaining frame, closing device and hinge pin, and nut for closing device.

For comparison purposes, Table 1 of this report was developed showing the permissible loadings in pounds per square inch units based on the formula given in ISO 5779. This table has good correlation with Table 1 of ISO 3903, which lists permissible loads in Pascal units.

ISO 5779 - "Ordinary Rectangular Windows - Positioning".

This standard provides the requirements for the positioning of ordinary (standard sizes only) rectangular windows for passenger and cargo ships intended for international voyages. The acceptability of a window position depends on its location relative to the length of the ship and height above the summer load line as well as the nature and the orientation of the superstructure or deckhouse structure in which it is fitted. No rectangular window shall be installed below the freeboard deck or in the first tier of superstructure or deckhouse sides which are within 1.2 meters of the ship's side. Shutters are required for rectangular windows in the first tier deckhouses, which give access to spaces below the freeboard deck and in the second tier, which give direct access to closed first tier superstructure or to spaces below the freeboard deck.

The expected maximum external forces (design pressure) are found by the calculation method given in Annex A of the document, which corresponds to British Standard BSMA 25 and International Association of Classification Societies unified requirement S3. No rectangular windows shall be installed in any part of the ship where the design pressure exceeds the maximum allowable pressure which individual types and sizes of rectangular windows can withstand, as given in Table 1 of the document.

The design pressure formula in Annex A, applies generally to the calculated load to which superstructures and deckhouses may be exposed. This design pressure is taken as a basis for the positioning of ships' rectangular windows when protecting openings according to Regulation 18 of 1966 International Load Line Convention (ILLC). Moreover, this formula included factors for height, location, over the vessel's length, probability and breadth of the vessel. Block coefficients are to be taken ranging from 0.6 to 0.8. The graphs in Annex B are based upon the calculation methods shown in Annex A and should only be used for general guidance, not to determine requirements.

General Comments on ISO Standards:

While the ISO standards form the "state of the art" information on which the national standards for the majority of the nations in the world are based, they are at best very difficult to utilize. Instead of issuing a single document for marine windows, ISO chose to fragment their design requirements and distribute them throughout several documents. This approach tends to lead to confusion and increases the chance of misunderstandings and errors.

If a decision is made to utilize ISO requirements, it is recommended that the existing ISO standards be combined into a single document.

B. British Standards Institute (BSI)

BS MA 25 - "Specification for Ships' Window"

This British standard specifies requirements for the design (including dimensions), construction, glazing, testing, and installation of non-opening and opening type windows for ships. It also specifies the thickness of toughened safety glasses for ships' windows located in the respective tier portions in both passenger and non-passenger ships. This standard is much more comprehensive than those of other organizations. It also provides all necessary information in one package rather than several separate documents.

The nominal dimensions and tolerances for fixed windows for sea-going ships are specified in Table 6 of the document, and the thickness of glass for standard window sizes are given in Tables 1 and 2 of the document.

Tables 1 and 2 provide glass thickness for different tiers and establish a "standard" thickness. The freeboard or bulkhead deck is established as the datum for determining height (tier) of the windows. A reduction of one thickness to the next lower thickness given in the table is provided for second tier and above if windows are positioned inboard from the side shell at least 4% of the breadth of the ship or 1.5m, whichever is greater, or positioned behind screens. While not specifically defined in the standard, a "screen" is any exterior structure providing some degree of protection from the weather to the superstructure bulkhead and adjacent deck area.

Table 1 provides requirements in an overly simplified method with very little explanation. This increases the chances of misunderstanding and error. Table 10 in Appendix E provides data for standard windows in clearer format, but it is still recommended that criteria and procedure for calculating thickness be provided to minimize the chance of error.

Windows for ships in restricted service are subject to the recommendation of Appendix D of the document, whereby the thickness of glasses for windows may be reduced according to the class of service. A minimum thickness of 6mm is specified for vessels in sheltered/inland waters.

Design pressure head can be determined from the formula given in Appendix E of the document. Design pressure heads for different tiers are limited by minimum pressure values.

The maximum allowable pressure head for toughened safety glass of standard size ships' windows is given in Table 10 of the document. The maximum allowable pressure head for windows on non-standard dimensions greater than those given in Table 10 may be calculated from the formula in E.2 of Appendix E. No rectangular windows shall be installed in any part of the ship where the design pressure exceeds the maximum allowable pressure which individual types and sizes of rectangular windows can withstand as given in the aforementioned table and formulation.

Glass is assumed to be supported on all sides by a frame which is fixed to the structure. For Category 1 front-facing opening windows, required glass thickness is to be increased one thickness to the next larger thickness given in Table 1 since the frame is not fully fixed to structure but can be considered to be locally clamped. For Category 1 sliding windows, glass thickness is to be the same as for fixed windows

since the frame is fully fixed. *Wheelhouse front windows* are considered "Category 1" and require glass thickness one thickness greater than noted in Table 1. Side windows are always regarded as Category 2 windows.

Cabin/public room windows protected by side screens may be 1 thickness less than Category 2 windows on same tier (10mm minimum). Interior windows (no weather loads) are to be 6 mm minimum thickness for framed windows less than 0.75 square meters in area and 10mm elsewhere.

Strength testing is done on a Batch test basis (2% sample of population), while ISO 3254 specifies testing for each piece.

The same point load type test is required as described in ISO 614.

BS MA 24 - "Specification for Ships' Scuttles".

This British standard specifies requirements for the design (including dimensions), construction, scantlings, glazing, testing, and installation and positioning of side scuttles for passenger and non-passenger ships.

Glasses for ships' side scuttles shall be of toughened safety glass. All edges shall be finished to remove sharpness and roughness.

The positioning of types of side scuttles have been determined according to the parameters of ship length, position above the load line, position lengthwise in the ship, and orientation in the side shell, front bulkheads or in the side bulkheads of superstructures.

In general, all technical requirements for side scuttles follow those set for windows in BS MA 25.

C. Swedish Standards Committee (SIS)

SS 78-02-67 - "Windows on Ships--Summary and Installation" (Proposed)

This document provides information on the dimensions, required glass thickness, and maximum pressure head for standard-size windows and scuttles for use on ships. All technical requirements are derived from the basic ISO standards.

SS 78-20-XX - "Windows in Cargo Ships--Positioning" (Proposed)

This proposed standard is based directly on ISO 5779 and is essentially a translation into Swedish.

SS-ISO-614 - "Toughened Safety Glass Panes for Ships' Side Scuttles and Ships' Rectangular Windows--Panel Method of Non-Destructive Strength Testing" (Proposed)

This proposed standard also is a Swedish translation of the existing ISO Standard 614.

D. Norwegian Standards Committee (NVS)

Norsk Standard NS 6149 - "Ships' Ordinary Rectangular Windows", 1980

As noted in the introductory paragraph for this document, this standard was issued as a Norwegian translation of ISO 3903.

Norsk Standard NS 6150 - "Toughened Safety Glass Panes for Ships' Rectangular Windows", 1980.

This document is a Norwegian translation of ISO 3254.

Norsk Standard NS 6153 "Ships' Side Scuttles and Ordinary Rectangular Windows--Openings and Installation", 1983.

This standard provides information on requirements of openings cut into structural bulkheads or shell for the installation of scuttles or windows.

E. Japanese Industrial Standards (JIS)

F2410-1978 - "Toughened Glasses for Ships' Side Scuttles"

This standard provides inspection and testing requirements for tempered glass for side scuttles. Both an impact test, in which a steel ball is dropped on a glass sample, and a water pressure (uniformly distributed) test are performed on glass samples. The uniform pressure

test load is based on the breaking strength of the glass with an approximate safety factor of 1.6.

F2402-1979 - "Ship's Hinged Rectangular Windows"

This document deals primarily with the frame assemblies for shipboard windows. Other standards are referenced (F3206) which concern the requirements for toughened glass.

F. Italian Registry of Naval Architecture (RINA)

Section 20.10--Rules - "Side Scuttles and Windows"

These rules apply to side scuttles and windows located in positions which are "exposed to the action of the sea and/or bad weather". The ship is divided into 8 zones; 3 below the freeboard deck and 5 in way of the superstructure. Types and maximum size of windows or scuttles are specified for each zone.

Tables 20.2 and 20.3 are provided to determine the required thickness of toughened glass and plate glass based on the zone in which the window is located and the length of the shorter side or the diameter for scuttles. When the length of the longer side is greater than twice the shorter side, thickness is determined by assuming that the "shorter side" length is one-third the sum of the two sides.

In larger passenger ships or those designed for high speed, thicknesses above those indicated in the tables may be required. Additionally, limitations may be imposed on the size of windows and the use of glasses of increased thickness in way of front bulkheads which are particularly exposed to heavy sea is required.

G. Det Norske Veritas

Section 3.D Rules - "Windows"

Windows in the sides and ends of superstructures and deckhouses are to be toughened safety glass. Minimum glass thickness is to be 5mm, but required thickness is to be calculated using the same method as for ISO.

Large glass doors or windows in the aft end of superstructure or deckhouse will be specially considered.

Windows of other materials than toughened safety glass, i.e. polycarbonate, are to be tested in the type of frame to be used to a test pressure of 4 times the lateral design pressure. The thickness is not to be less than 5 mm.

H. International Council of Marine Industries Association (ICOMIA)

ICOMIA Standard No. 9 - "Windows and Portlights"

This standard applies to craft of up to 15 meters (49 feet) in length.

For craft restricted to sheltered and in-shore water, except for helmsman's screens normally fitted at the fore end of cockpits, the thickness of the windows may not be less than 4mm.

The minimum thickness of glass or acrylic sheet for craft operated in unprotected waters is to be taken from the appended tables subject to several provisions. In no case may the thickness of the glass be less than 5mm.

2. U.S. Government Specifications

A. **Interim Federal Specification DD-G-001403** - "Glass Plate (Float), Sheet, Figured & Spandrel (Heat Strengthened and Fully Tempered)"

This document provides production tolerances and quality assurance requirements for glass manufacturing as well as technical information for the design of windows.

Fully tempered glass is required to have surface compression of not less than 10 ksi and edge compression not less than 9.7 ksi. Table V provides the minimum average breaking pressure for standard thicknesses of tempered glass.

Impact strength requirements and testing are referred to ANSI Standard Z97.1. Table VIII provides maximum window area versus wind pressure for the standard glass thicknesses with a design safety factor of 2.5.

B. **Federal Specification DD-G-451C** - "Glass, Plate, Sheet, Figured (Float, Flat, For Glazing, Corrugated, Mirrors, and Other Uses)"

C. **MIL-G-2857A** - "Glass, Heat-Treated, Glazing, Rectangular (for Bridge Windows)"

D. **MIL-G-3787G** - "Glass Laminated, Flat; (Except Aircraft)"

E. **MIL-W-18445D** - "Windows, Non-Icing, Laminated Flat glass, Electrically Heated With Controls"

F. **MIL-G-8602 A (Cancelled)** - "Glass, Laminated, Flat, Aircraft"

Each of the above documents is a material specification providing basis production tolerances and quality assurance requirements for the particular types of glass covered. No information is provided for allowable load or stresses or structural characteristics. It is noted that non-tempered glass is used for laminated windows produced in accordance with MIL-G-3787G.

3. Related Literature

A. International Association of Classification Societies (IACS) Standards For the Deckhouse and Superstructures:

Unified Requirement S3 specifies a formulation for external pressure given as head of water. The formulation contains factors that account for the effects of:

1. orientation and degree of protection,
2. correction of relative motion fore and aft as well as influence of speed, it is a function of longitudinal location and block coefficient ($0.6 < C_B < 0.8$)
3. correction for deckhouses with small breadth relative to the maximum breadth of the ship,
4. relative motion amidships and is a function of the ship length,
5. minimum pressure in cases where the external water pressure is small. The pressure head is not to be taken as less than 3 meters

or 4.5 psi. Minimum thickness of plating is 6.0 mm for lowest tier of fronts, sides, and after ends and 5.0 mm elsewhere.

The basis of this standard was developed from the calculation of long-term statistical distribution of the relative motion in the vertical direction between the ship and wave. It appears that wave impact loads were not directly considered.

Moreover, this standard supports a decrease of scantlings for smaller ships but not necessarily an increase for larger ships because damage records of superstructures and deckhouses are scarce and available statistics seem to indicate that medium size ships have more reports of damage. In general, this result seems consistent with respect to the motion characteristics of ship sizes and their intended region of operation.

ABS Rules for superstructure and deckhouse are basically the same as the IACS Standard.

B. PPG Industries Technical Service Report No. 101 - "Glass Product Recommendations--Structural"

This document provides reference data of a general nature to assist architects, engineers, and regulatory authorities in design to meet wind load requirements.

The stress required to break a large light of glass is related to temper, fabrication surface quality, support conditions, and type of loading. A relationship of loading to breaking stresses to different type of loading and corresponding approximated load duration is provided in the document.

It also suggests that when the effect of service conditions cannot be predicted accurately for the life span of a building, the designer should make allowance for contingencies by increasing the safety factor, above the minimum recommended value of 2.5 for U.S. Weather Bureau, fastest mile wind load (50-year recurrence interval). A relationship of safety factors to the statistical probability of failure is provided in the document.

A formulation for calculating wind load design of glass in rectangular buildings is given in terms of a correction factor for elevation, a

correction factor for gusts, the fastest mile wind velocity for elevation of 30 feet above ground (50-year recurrence interval) from U.S. Weather Bureau records, and a correction factor for building shape.

The document further states that a glass thickness which may be adequate to resist the uniform loads to which it is exposed may not be thick enough to resist concentrated loads applied by spike heels, dropped tools, rifle pellets, balls, stones, human appendages, food trays, shopping carts, hospital beds, diamond rings, etc. Even when such things have relatively low velocity, mass, and momentum, the possibility is real that point loading stresses may exceed the breakage level.

C. **Damage Due to Shipping Green Water and Design Standard** - International Ship Structure Committee 5th ISSC Report, No. 8, September, 1973.

Design water head or the equivalent static water head estimated inversely from available ship damage data was established for various structural members as a function of ship length.

It is to be noted that the values of design water head up to 40 ton/m^2 (56.4 psi) apply to some members, such as the stiffener of the forward bulkhead of the superstructure, to prevent structural damage due to green water.

D. **Stochastic Prediction of Impact Pressure Due to Shipping Green Sea on Fore Deck of Large Ore Carrier Ship** - by Masuo Kawakami and Kazumasa Tanaka, Transactions of J.S.N.A., Japan, No. 53, March 1977.

Long-term prediction of impact pressure on each heading for average wave size was carried out for the North Atlantic Ocean. The predicted magnitude of impact pressures exceeding a probability of 10^{-8} can reach 46 ton/m^2 (64.9 psi) for Froude Number = 0.15, 37.6 ton/m^2 (53.0 psi) for Fr = 0.125 and 27.5 ton/m^2 (38.8 psi) for Fr = 0.1 in winds equal to Beaufort Scale 10 - 11.

E. **Breaking Waves - The Plunging Jet and Interior Flow Field** - by E.D. Cokelet.

As deep-water waves increase in steepness and overturn, a jet of water is ejected from the wavecrest. Once the jet is well formed, there is a substantial region of horizontal velocity feeding water into the jet, and there is an indication that the fluid is being accelerated due to large horizontal pressure gradients. The maximum acceleration shown in sample calculations can be as high as 1.6g, which is above 3 times that of the highest steady wave.

Calculations indicated that fluid speeds can exceed 1.3 $(g/k)^{1/2}$ in the breaking region. Maximum acceleration approaches 1.0 g and can have appreciable horizontal components.

F. **On the Impact Strength of Ship Due to Shipping Green Seas** - by Masuo Kawakami, Transaction of J.S.N.A. Japan, Vol. 125, June, 1969--Towing Experiments of a Ship Model in Regular Waves.

The maximum impact pressure on the forecastle deck can reach 50 ton/m^2 (72 psi) in the most severe weather conditions. The time duration of impact pressure due to shipping green water was 0.2 to 0.3 seconds and was only observed for the model. It is suggested that the duration time for the actual ship be analyzed based on the similarity law of shipping wave impact phenomena.

If the model was towed in a beam sea condition instead of head sea as in this experiment, the maximum impact pressures due to shipping green seas may occur at different speeds and in different deck areas.

G. **Changes in the Tensile Strength of Glass Caused by Water Immersion** - by G.F. Stockdale, F.V. Tooley, and C.W. Ying, Journal of American Ceramics, Society Volume 34(4), Pages 116-121.

This report details the results of a study performed to determine the effects of water immersion of glass on the strength of the material. Three types of commercial glass were tested both in air and immersed in distilled water, with a number of samples having been totally immersed in water for periods of up to 1056 hours.

These tests indicate that fresh samples broken under water have a marked decrease in strength when compared to samples broken in air. This is probably due to increased stresses caused by the hydrostatic pressure of water in microscopic surface flaws in the glass or stress-enhanced corrosion at the flaw tip.

Test samples which had been soaked in water for a period of time showed a marked increase in strength. It is assumed that this is due to the corrosive action of the water "blunting" the flaw tips.

H. **Stress Measurements in Tempered Glass Plates by Scattered Light Method With a Laser Source** - by S. Bateson, J.W. Hunt, D.A. Dalby, and N.K. Sinka, American Ceramic Society Bulletin, Volume 45(2), Pages 193-198, 1966.

This report discusses the results of experiments in the use of a Helium-Neon laser for photoelastic observation by the scattered light technique to determine central plane stresses.

The tests performed indicate that this technique provides an accurate measurement of central plane principal stresses for even very large sheets of tempered glass on thicknesses down to 3/16 inch.

I. **The Strength of Weathered Window Glass Using Surface Characteristics** - by J.J. Abiassi, Texas Tech University, Glass Research and Testing Laboratory Report 61D, August, 1981.

This report discusses the results of experimental strength tests on samples of new and weathered window (plate) glass. While no testing was performed on tempered glass, the discussions and test results contained in the report are still useful for the general tendencies of glass degradation due to exposure to the weather.

An explanation of the glass failure mechanism is provided as an introduction along with a discussion of the history of the various "methods" developed to model the strength of plate glass.

Strength tests were performed on a large number of samples of both new window glass and 15-20 year old glass obtained from existing buildings. As a result of these tests, it was found that the strength of old (weathered) window glass is, in fact, significantly less than that of

new glass; some samples of weathered glass having failed at loads up to 50% less than the new samples. Additionally, it was found that old glass is weaker when the unweathered side is put in tension than when its weathered side is in tension. Apparently, this is due to reduced flaw tip rounding by corrosion on the protected (unweathered) side.

J. **The Strength of New Window Glass Plate Using Surface Characteristics** - by D.C. Kanabolo and H.S. Norville, Texas Tech University Glass Research and Testing Laboratory Report 76D, July, 1985.

While this report dealt strictly with window glass, it provides useful information on the general strength characteristics of glass. Numerous strength tests were performed on a variety of sample sizes and aspect ratio.

The results of these tests indicate that:

1. Glass strength is highly dependent on loading rate--shorter duration results in higher breaking loads.

2. Failure load decreases markedly with increasing glass areas with a common aspect ratio.

3. For constant surface area, failure load increases with decreasing aspect ratio. This change in load is less pronounced with increasing surface area.

TECHNICAL DISCUSSION

1. General:

Glass may be considered a homogenous, isotropic material which follows simple elastic theory up to its point of failure. Since glass fails suddenly without prior permanent deformation, it is considered a brittle material.

In general, glass failure results from a tensile stress in combination with a defect at a surface flaw, acting as a stress concentrator. Glass is many times stronger under pure compressive loads than when subjected to a tensile load. Therefore, compressive stresses and shear stresses are usually not considered, except in cases where, due to the geometries and loading conditions, associated tensile stresses are produced at the surface.

Surface defects come from a variety of causes and are found in many forms. They can be from the manufacturing process, thermal and mechanical in origin, or they can result from handling, packaging, shipping, installation, and end-use operation. A solid inclusion within the glass produces a potential fracture surface at the inclusion-glass boundary. Solid inclusions should not be permitted, especially in tempered (toughened) or chemically-strengthened (ion-exchanged) glass in which high tensile stresses are generated in the central portions of the glass body.

Based on glass industry experience, the relationship between surface flaw depth and tensile stress for failure can be approximated by the following:

$$\sigma(t)^{1/2} = 500 \qquad \text{(ref. Inglis--Semi Elliptical Flaw)}$$

σ = stress required for spontaneous failure, psi

t = crack depth, inches

Thus for a crack depth of 0.010", spontaneous failure is produced by a tensile stress of 5000 psi. However, slow crack growth in the presence of a polar liquid (water vapor) will produce delayed failure at a stress half this value, 2500 psi. This is referred to as static fatigue or stress-time in which water becomes a stress-enhanced corrosive agent at the crack tip causing it to grow to critical depth, 0.04".

2. Design Strength:

The existing standards for marine windows are essentially consistent in their design approach, using the same basic design equation to relate the expected load to the required minimum glass thickness. In no case, however, do any of these documents provide guidance on the allowable stress levels upon which the design equations were

based. Since each standard does require a flexible glazing system to secure the window in its frame, it is possible to treat the glass as a flat plate simply supported on all four sides.

Using Roarke's handbook, Formulas for Stress and Strain, case 36 on page 225 (Bibliography reference I6) along with the dimensional data provided for the "standard" windows described in the existing documents, it is possible to calculate an approximate maximum tensile stress at the glass surface. Tables 1, 2, and 3 present the dimensions and calculated loads and stresses for the ISO, British, and Swedish standards, respectively. Based on this analysis, the allowable design stress for tempered glass was found to range between 5790 and 6018 psi for the standard sized windows.

These results correlate quite well with glass industry documentation of the same period, such as Technical Service Report No. 101 (reference H1), which was prepared by PPG Industries in the late 1960's. In their reports on window glass strength using surface characteristics, Texas Tech University (references I1 and I2) noted that PPG used a finite element technique and the results of many destructive tests on glass panels to obtain a mean limiting value for the 60-second failure stress of 6000 psi for float plate glass. The use of this value and normal industry failure rates reflects a safety factor of 2.5 on the breaking strength of the glass.

Figure 2 of PPG Industries Technical Service Report 101 (reference H1) provides a listing of the ultimate or breaking strength of glass under loads of differing duration. For wind pressure loads of 1 minute, a breaking stress of 20,000 psi is considered typical.

Using the breaking strength data provided in Federal Specification DD-G-001403 and the dimensional data for ISO and British Standard windows, Table 4 was developed to provide a comparison of allowable pressure loads and breaking loads for standard windows. From Formulas for Stress and Strain (reference I6), case 36, page 225, the tensile stress at the surface of a flat plate supported on all sides can be related to a uniformly distributed load by the equation:

$$\sigma = \beta w (b/t)^2$$

σ = maximum tensile stress at surface

β = dimensional factor based on aspect ratio of plate

b = minor dimension (width) of plate

t = thickness of plate

w = uniformly distributed load

a	b	Aspect Ratio	Thickness		Beta (Pressure)	Pressure	Stress
(in.)	(in.)		(mm.)	(in.)		(psi)	(psi)
16.7323	11.8110	1.4167	8	0.3150	0.4600	9.02	5878.01
16.7323	11.8110	1.4167	10	0.3937	0.4600	14.09	5879.51
19.6850	13.9764	1.4085	8	0.3150	0.4500	6.58	5939.96
19.6850	13.9764	1.4085	10	0.3937	0.4500	10.28	5941.47
22.0472	15.7480	1.4000	8	0.3150	0.4500	5.18	5869.99
22.0472	15.7480	1.4000	12	0.4724	0.4500	11.67	5872.47
24.8031	17.7165	1.4000	8	0.3150	0.4500	4.10	5869.99
24.8031	17.7165	1.4000	12	0.4724	0.4500	9.22	5872.47
27.9528	19.6850	1.4200	10	0.3937	0.4600	5.07	5824.98
27.9528	19.6850	1.4200	15	0.5906	0.4600	11.41	5824.00
31.4961	22.0472	1.4286	10	0.3937	0.4622	4.02	5832.59
31.4961	22.0472	1.4286	15	0.5906	0.4622	9.05	5831.60
35.4331	24.8031	1.4286	12	0.4724	0.4622	4.58	5833.58
35.4331	24.8031	1.4286	19	0.7480	0.4622	11.48	5833.06
39.3701	27.9528	1.4085	12	0.4724	0.4500	3.70	5907.47
39.3701	27.9528	1.4085	19	0.7480	0.4500	9.28	5906.95
43.3071	31.4961	1.3750	15	0.5906	0.4434	4.62	5831.60

Table 1 Allowable Stresses for Standard Windows
ISO Standard (ISO 3254)

a	b	Aspect Ratio	Thickness		Beta (Pressure)	Pressure	Stress
(in.)	(in.)		(mm.)	(in.)		(psi)	(psi)
16.7323	11.8110	1.4167	10	0.3937	0.4600	14.09	5813.57
16.7323	11.8110	1.4167	12	0.4724	0.4600	20.29	5814.56
16.7323	11.8110	1.4167	15	0.5906	0.4600	31.70	5812.59
16.7323	11.8110	1.4167	19	1.7480	0.4600	50.86	5814.04
19.6850	13.9764	1.4085	10	0.3937	0.4500	10.28	5906.47
19.6850	13.9764	1.4085	12	0.4724	0.4500	14.81	5907.47
19.6850	13.9764	1.4085	15	0.5906	0.4500	23.14	5905.47
19.6850	13.9764	1.4085	19	0.7480	0.4500	37.13	5906.95
22.0472	15.7480	1.4000	10	0.3937	0.4500	8.10	5871.48
22.0472	15.7480	1.4000	12	0.4724	0.4500	11.67	5872.47
22.0472	15.7480	1.4000	15	0.5906	0.4500	18.23	5870.48
22.0472	15.7480	1.4000	19	0.7480	0.4500	29.24	5871.95
24.8031	17.7165	1.4000	10	0.3937	0.4500	6.40	5871.48
24.8031	17.7165	1.4000	12	0.4724	0.4500	9.22	5872.47
24.8031	17.7165	1.4000	15	0.5906	0.4500	14.40	5870.48
24.8031	17.7165	1.4000	19	0.7480	0.4500	23.11	5871.95
27.9528	19.6850	1.4200	10	0.3937	0.4600	5.07	5824.98
27.9528	19.6850	1.4200	12	0.4724	0.4600	7.30	5825.97
27.9528	19.6850	1.4200	15	0.5906	0.4600	11.41	5824.00
27.9528	19.6850	1.4200	19	0.7480	0.4600	18.31	5825.45
31.4961	22.0472	1.4286	10	0.3937	0.4622	4.02	5832.59
31.4961	22.0472	1.4286	12	0.4724	0.4622	5.79	5833.58
31.4961	22.0472	1.4286	15	0.5906	0.4622	9.05	5831.60
31.4961	22.0472	1.4286	19	0.7480	0.4622	14.53	5833.06
35.4331	24.8031	1.4286	10	0.3937	0.4622	3.18	5832.59
35.4331	24.8031	1.4286	12	0.4724	0.4622	4.58	5833.58
35.4331	24.8031	1.4286	15	0.5906	0.4622	7.15	5831.60
35.4331	24.8031	1.4286	19	0.7480	0.4622	11.48	5833.06
39.3701	27.9528	1.4085	12	0.4724	0.4500	3.70	5907.47
39.3701	27.9528	1.4085	15	0.5904	0.4500	5.79	5905.47
39.3701	27.9528	1.4085	19	0.7480	0.4500	9.28	5906.95
43.3071	31.4961	1.3750	15	0.5906	0.4434	4.62	5831.60
43.3071	31.4961	1.3750	19	0.7480	0.4434	7.42	5833.06

Table 2 Allowable Stresses for Standard Windows British Standard (BS MA 25)

a	b	Aspect Ratio	Thickness		Beta (Pressure)	Pressure	Stress
(in.)	(in.)		(mm.)	(in.)		(psi)	(psi)
24.8031	17.7165	1.4000	12	0.4724	0.4500	9.22	5872.47
24.8031	17.7165	1.4000	19	0.7480	0.4500	23.11	5871.95
27.9528	19.6850	1.4200	15	0.5906	0.4600	11.41	5824.00
31.4961	22.0472	1.4286	15	0.5906	0.4622	9.10	5859.50
39.3701	17.7165	2.2200	15	0.5906	0.6375	10.17	5789.94
39.3701	29.5276	1.3300	15	0.5906	0.4250	5.49	5846.70
41.3386	39.3701	1.0500	15	0.5906	0.3000	4.37	6018.22
53.1496	39.3701	1.3500	19	0.7480	0.4375	4.81	5783.73
64.9606	39.3701	1.6500	19	0.7480	0.5375	3.92	5833.06

Table 3 Allowable Stresses for Standard Windows
Swedish Standard (SIS 38)

a (in.)	b (in.)	Area (sq.ft.)	Thickness (in) STD	Thickness (in) FED SP	FED SPEC Breaking Load(psi)	ISO Allow Load(psi)	ISO Safety Factor	BS MA 25 Allow Load(psi)	BS MA 25 Safety Factor
16.7323	11.8110	1.4167	0.3150	0.3125	37.19	9.02	4.12	N/A	N/A
16.7323	11.8110	1.4167	0.3937	0.3906	60.72	14.09	4.31	14.09	4.31
16.7323	11.8110	1.4167	0.5000	0.4724	80.96	N/A	N/A	20.29	3.99
19.6850	13.9764	1.4805	0.3150	0.3125	26.72	6.58	4.06	N/A	N/A
19.6850	13.9764	1.4085	0.3937	0.3906	43.62	10.29	4.24	10.28	4.24
19.6850	13.9764	1.4085	0.5000	0.4724	58.16	N/A	N/A	14.81	3.93
22.0470	15.7480	2.4110	0.3150	0.3125	21.17	5.19	4.08	N/A	N/A
22.0472	15.7480	2.4110	0.3937	0.3906	34.56	N/A	N/A	8.10	4.27
22.0472	15.7480	2.4110	0.4724	0.5000	46.09	11.67	3.95	11.67	3.95
24.8031	17.7165	3.0520	0.3150	0.3125	16.50	4.10	4.02	N/A	N/A
24.8031	17.7165	3.0520	0.3937	0.3906	27.31	N/A	N/A	6.40	4.27
24.8031	17.7165	3.0520	0.4724	0.5000	36.41	9.22	3.95	9.22	3.95
27.9528	19.6850	3.8210	0.3937	0.3906	21.81	5.07	4.30	N/A	N/A
27.9528	19.6850	3.8210	0.4724	0.5000	29.08	N/A	N/A	7.30	3.98
31.4961	22.0472	4.8220	0.3937	0.3906	17.28	4.02	4.30	4.02	4.30
31.4961	22.0472	4.8220	0.4724	0.5000	23.04	N/A	N/A	5.79	3.98
35.4331	24.8031	6.1030	0.3937	0.3906	13.66	N/A	N/A	3.18	4.29
35.4331	24.8031	6.1030	0.4724	0.5000	18.21	4.58	3.98	4.58	3.98
39.3701	27.9528	7.6420	0.4724	0.5000	14.54	3.70	3.93	3.70	3.93

Table 4 Comparison of Allowable Loads & Safety Factors Based on FED SPEC DD-G-1403 Breaking Pressures

Consequently, based on the ratios of breaking to allowable loads, it was possible to multiply the previously calculated allowable stresses by the load safety factors to obtain an approximate breaking stress for the ISO and British standard windows. As can be seen in the summary provided by Table 5, the range of calculated breaking stresses obtained (approximately 23,000 psi) indicate that the industry-recommended values for breaking stress (20,000 psi) as represented in Fed. Spec. DD-6-1403 (Reference G1) are somewhat conservative but still acceptable for standard marine windows.

As previously noted, flaw size is critical to the failure of glass windows since surface flaws act as stress concentrations which locally increase tensile stresses until brittle fracture occurs, initiated at the flaw tip. The research efforts which resulted in the establishing of 6000 psi as the allowable surface tension in glass plate were based on experimental testing of numerous samples to destruction. Surface conditions for experimental samples do not necessarily reflect those of a production item. Handling, mounting of glass windows in their frame assemblies, and installation onboard the ship can each result in scratches and chips in the glass surfaces, especially at the edges, which can reduce the effective strength of the panel.

In reference I7, E.B. Shand recommends that tensile working stresses be limited to maximum values of 1000 psi for annealed glass and between 1500 and 4000 psi for tempered glass. These lower values were selected based on experiment data with allowances for variation in load duration. In essence, the allowable working stress in the glass industry is revised downward to allow for handling damage, normal service wear and tear, and the uncertainties over the duration of the loads to which the glass will be subjected.

In general, research performed to date, including the study conducted at Texas Tech University reported by reference I1, indicates that overall glass strength decreases with age. From additional analysis of Texas Tech data, the unweathered glass surface (inside surface) is considerably weaker than the weathered surface. This result may be due to the inside surface being cleaned more often with increased scratching and abrasion. Additionally, the outside (weathered) glass surface is subject to increased flaw tip rounding due to weathering. Without a tensile stress present, glass actually gets somewhat stronger with time in the presence of water vapor, as shown by the research performed by Stockdale, reported in reference I3. Here water is still viewed as a corrosive agent, but not stress-enhanced, and the flaw tip gets blunted rather than propagated. However, it must be noted that the test samples used for this report were totally immersed in water while windows onboard a vessel will be exposed to the sea environment on one side only and will be subjected to both positive and negative pressure loads on the exposed surface. Surface flaws (or damage) on the protected side will be subjected to corrosion to a much lesser degree than on the exposed surface. Since the inside surface sees a tensile stress under exterior pressure load, the window can be expected to fail at lower loads as it ages.

a (in.)	b (in.)	Area (sq.ft.)	Thickness (in.)	ISO Safety Factor	ISO Allow. Stress (psi)	ISO Breaking Stress (psi)	BS MA 25 Safety Factor	BS MA 25 Allow. Stress (psi)	BS MA 25 Breaking Stress (psi)
16.7323	11.8110	1.4167	0.3150	4.12	5878.01	24217	N/A	N/A	N/A
16.7323	11.8110	1.4167	0.3937	4.31	5879.51	25341	4.31	5813.57	25056
16.7323	11.8110	1.4167	0.5000	N/A	N/A	N/A	3.99	5814.56	23200
19.6850	13.9764	1.4805	0.3150	4.06	5939.96	24116	N/A	N/A	N/A
19.6850	13.9764	1.4085	0.3937	4.24	5941.47	25192	4.24	5906.47	25043
19.6850	13.9764	1.4085	0.5000	N/A	N/A	N/A	3.93	5907.47	23216
22.0472	15.7480	2.4110	0.3150	4.08	5869.99	23950	N/A	N/A	N/A
22.0472	15.7480	2.4110	0.3937	N/A	N/A	N/A	4.27	5871.48	25071
22.0472	15.7480	2.4110	0.4724	3.95	5872.47	23196	3.95	5872.47	23196
24.8031	17.7165	3.0520	0.3150	4.02	5869.99	23597	N/A	N/A	N/A
24.8031	17.7165	3.0520	0.3937	N/A	N/A	N/A	4.27	5871.48	25071
24.8031	17.7165	3.0520	0.4724	3.95	5872.47	23196	3.95	5872.47	23196
27.9528	19.6850	3.8210	0.3937	4.30	5824.98	25047	N/A	N/A	N/A
27.9528	19.6850	3.8210	0.4724	N/A	N/A	N/A	3.98	5825.97	23187
31.4961	22.0472	4.8220	0.3937	4.30	5832.59	25080	4.30	5832.59	25080
31.4961	22.0472	4.8220	0.4724	N/A	N/A	N/A	3.98	5833.58	23218
35.4331	24.8031	6.1030	0.3937	N/A	N/A	N/A	4.29	5832.59	25022
35.4331	24.8031	6.1030	0.4724	3.98	5833.58	23218	3.98	5833.58	23218
39.3701	27.9528	7.6420	0.4724	3.93	5907.47	23216	3.93	5907.47	23216

Table 5 Approximate Breaking Stress for ISO & British Standard Windows

As window glass area is increased, the probability of the presence of a surface flaw large enough to cause failure at a lower than expected stress level increases. Tests on window glass performed at Texas Tech University (reference I2) clearly indicate that failure load decreases with increasing area for a common aspect ratio. As a result, the report concluded that predicted strength should be reduced as window area increases. While this study was performed on common window glass, it is reasonable to assume that tempered glass will display similar characteristics.

Information on chemically-strengthened glass is very limited. ASTM specification section C162-80 defines chemically-strengthened glass as: "glass that has been ion-exchanged to produce a compressive stress layer at the treated surface."

In reference I9, Hagy reports that a chemically-strengthened glass similar in composition to glass code 0311 was experimentally tested and found to have a fracture stress of 40,000 psi. Employing the design safety factor of 2.5, typically used by the glass industry, this would result in an allowable working stress of 16,000 psi, or four times greater than the recommended maximum working stress for tempered glass.

3. Design Loads:

Each of the existing marine window standards provides a method for determining minimum thickness requirements for window sizes differing from those provided in the document. Generally, minimum glass thickness is related to pressure head (height of a column of water) by the equation:

$$H = 4000t^2/\beta b^2 \qquad \text{(ref. ISO 3254)}$$

where

H = maximum allowable pressure head in meters

t = glass thickness in millimeters

β = dimensional factor based on aspect ratio of glass panel

b = minor dimension of window in millimeters

In some cases, the equation is modified to yield design pressure rather than pressure head. For these cases, the 4000 on the right hand side of the equation is reduced to 40 to obtain the pressure in millipascals (N/mm^2).

The critical aspect in determining window thickness, therefore, becomes the determination of the design pressure or pressure head for which the glass is sized. Pressure is directly related to the location of the window on the vessel as well as the degree to which it is exposed. In general, shipbuilding design practice dictates locating windows high enough on the side shell or superstructure to minimize the chance of wave impacts.

Each of the existing standards uses the formulation developed by the International Association of Classification Societies (IACS) Unified Requirement S3 (Ref. 3A) for the design of superstructures and deckhouses. This method has been incorporated as Sections 17.3.2 and 17.3.3 of the ABS Rules for Steel Vessels. The equation for design load was developed from long-term statistical distribution data for waves and relative motion of the ship, modified to reflect actual operating experience. No problems have been encountered with deck houses or superstructures designed to this standard. In general, this technique provides relatively realistic pressure heads which are imposed over large areas of the structure. From our research, it appears that the effects of wave impacts or localized peak loads were not considered.

Pressure head is defined by the following equation:

$$h = a\,[(bf) - y]\,c$$

(ABS Rules for Steel Vessels, Section 17.3.2)

where,

h = the design head. For unprotected front bulkheads on the lowest tier, h is to be taken as not less than 8.2 + L/100 ft, in which L need not be taken as greater than 820 ft. For all other bulkheads, the minimum value of h is to be not less than one-half the minimum required for unprotected front bulkheads on the lowest tier.

a = coefficient given in Table 17.1 of ABS Rules.

b = $1.0 + [\frac{(x/L) - 0.45}{Cb + 0.2}]^2$ where $x/L \leq 0.45$

= $1.0 \; 1.5 [\frac{(x/L) - 0.45}{Cb + 0.2}]^2$ where $x/L > 0.45$

Cb = block coefficient at summer load waterline, not to be taken as less than 0.60 nor greater than 0.80.

x = distance between the after perpendicular and the bulkhead being considered.

L, L_2 = length of vessel, but L_2 need not be taken as greater than 984 ft.

f = coefficient given in Table 17.2 of ABS Rules.

y = vertical distance from the summer load waterline to the midpoint of the stiffener span.

c = $(0.3 + 0.7\, b_1/B_1)$, but is not be taken as less than 1.0 for exposed machinery casing bulkheads. In no case is b_1/B_1 to be taken as less than 0.25.

b_1 = breadth of deckhouse at the position being considered.

B_1 = actual breadth of the vessel at the freeboard deck at the position being considered.

As an example, pressure head is calculated for a "typical" vessel as a function of the height above the design waterline. The following characteristics were assumed:

length = 500 ft. block coefficient = 0.65

design draft = 20 ft. design depth = 40 ft.

superstructure tiers each 10 ft. high located amidship

Table 6 summarizes the results of this calculation and provides the uniform pressure distribution. Typical of the design pressure and head distributions obtained from all the existing glass standards, pressure (head) decreases as the height above waterline increases.

Height Above Sea Level (ft.)	Pressure Head (ft.)	Pressure (psi)	Location
0	98.92	42.84	Shell
5	82.57	35.76	Shell
10	66.22	28.68	Shell
15	49.87	21.60	Shell
20	33.52	14.52	Shell
25	17.17	7.44	1st Tier
30	6.60	2.86	1st Tier
40	6.60	2.86	2nd Tier
50	6.60	2.86	3rd Tier
60	6.60	2.86	4th Tier
70	6.60	2.86	5th Tier
80	6.60	2.86	6th Tier
100	6.60	2.86	7th Tier

Table 6
ABS Pressure Head for Typical Vessel

Height Above Sea Level (ft.)	V/V(30)	Wind Velocity		Wind Pressure	
		Mi./Hr.	Ft./Sec.	psf	psi
0	0.0000	0.00	0.00	0.00	0.000
1	0.3218	32.18	47.20	7.13	0.050
5	0.5503	55.03	80.72	20.85	0.145
10	0.6934	69.34	101.70	33.09	0.230
15	0.7937	79.37	116.41	43.37	0.301
20	0.8736	87.36	128.13	52.32	0.365
25	0.9410	94.10	138.02	60.96	0.423
30	1.0000	100.00	146.67	68.84	0.478
35	1.0223	102.23	149.94	71.94	0.500
40	1.0420	104.20	152.83	74.74	0.519
45	1.0597	105.97	155.42	77.30	0.537
50	1.0757	107.57	157.78	79.66	0.553
60	1.1041	110.41	161.94	83.92	0.583
70	1.1287	112.87	165.55	87.70	0.609
80	1.1505	115.05	168.74	91.11	0.633
90	1.1700	117.00	171.60	94.23	0.654
100	1.1877	118.77	174.21	97.11	0.674

Table 7
Wind Velocity & Pressure Versus Elevation
(Based on 100 MPH Wind 30 Ft. Above Sea Level)

In the building construction industry, architectural glass window design loads are based on wind velocity. Generally, the U.S. Weather Bureau fastest mile wind load for a 50-year recurrence interval is used. The impact loads due to wind gusts or extreme loads such as tornadoes are not usually considered for buildings unless specifically required by code. For buildings, the design wind velocity and pressure increases as the height above sea level increases.

Table 7 provides a comparison of wind velocity and pressure as a function of height above sea level based on a 100 mile per hour wind at a height of 30 feet above sea level. This corresponds to hurricane conditions with a wind force equal to Beaufort 12 and sea state 9. In comparison to the results of Table 6, the wind pressures are much less than the design pressures obtained from the existing marine standards.

In the Handbook of Ocean and Underwater Engineering (reference I5), C.L. Bretschneider notes that wind velocity pressure formulas generally only consider the load created by dry wind impinging upon a body. In the marine environment, high winds are often accompanied by rain or wind-blown spray. Because water is approximately 800 times as dense as air, a small amount of entrained water will significantly increase the pressure.

Wind force can be defined by the equation:

$$F = (Awv^2)/(2g)$$

(Ref. I8 Ocean Engineering Structures, pg. 29)

where,

F = wind force

A = projected area

w = unit weight of air/water

v = wind velocity

g = acceleration of gravity

Since the unit weight can be expressed as a function of the percentage by volume of entrained water, it is possible to determine the approximate wind force on a body for specific wind velocities and water content. Table 8 provides a listing of total wind force as a function of both wind velocity and the percentage of entrained water. When compared to the data in Table 7, the load for a wind velocity of 100 miles per hour with a 2% volume of entrained water will increase by over 13 times the wind load without entrained water.

Percent Entrained Water	Total Density (lb/ft^3)	Wind Velocity (miles/hour)									
		10	20	30	40	50	60	70	80	90	100
0.10	0.144	0.0067	0.0267	0.0601	0.1068	0.1669	0.2403	0.3271	0.4273	0.5408	0.6676
0.20	0.208	0.0096	0.0386	0.0868	0.1543	0.2410	0.3471	0.4724	0.6171	0.7810	0.9641
0.30	0.272	0.0126	0.0504	0.1135	0.2017	0.3152	0.4538	0.6177	0.8068	1.0211	1.2607
0.40	0.336	0.0156	0.0623	0.1401	0.2491	0.3893	0.5606	0.7630	0.9966	1.2613	1.5572
0.30	0.272	0.0126	0.0504	0.1135	0.2017	0.3152	0.4538	0.6177	0.8068	1.0211	1.2607
0.40	0.336	0.0156	0.0623	0.1401	0.2491	0.3893	0.5606	0.7630	0.9966	1.2613	1.5572
0.50	0.400	0.0185	0.0741	0.1668	0.2966	0.4634	0.6673	0.9083	1.1864	1.5015	1.8537
0.60	0.464	0.0215	0.0860	0.1935	0.3440	0.5376	0.7741	1.0536	1.3761	1.7417	2.1502
0.70	0.527	0.0245	0.0979	0.2202	0.3915	0.6117	0.8808	1.1989	1.5659	1.9819	2.4467
0.80	0.591	0.0274	0.1097	0.2469	0.4389	0.6858	0.9876	1.3442	1.7557	2.2220	2.7433
0.90	0.655	0.0304	0.1216	0.2736	0.4864	0.7599	1.0943	1.4895	1.9455	2.4622	3.0398
1.00	0.719	0.0334	0.1335	0.3003	0.5338	0.8341	1.2011	1.6348	2.1352	2.7024	3.3363
1.50	1.039	0.0482	0.1928	0.4337	0.7710	1.2047	1.7348	2.3613	3.0841	3.9033	4.8189
2.00	1.358	0.0630	0.2521	0.5671	1.0082	1.5754	2.2685	3.0877	4.0329	5.1042	6.3015

Table 8
Uniform Pressure (psi) Produced by Moisture Bearing Wind

In regard to determining the actual resultant load on ships' windows from the combined effects of wind and wave in a particular sea state, a simplified solution does not presently exist. However, it is possible to perform an analysis to determine the resultant load based on ship motion studies, green water studies, wave impact studies, and wind pressures. This analytical method of load determination could be verified by full-scale measurements or model testing.

However, the present method of determining loads on deckhouses from classification society rules has apparently given satisfactory results, based on the lack of widespread casualty reports on existing windows.

4. Testing and Quality Assurance:

The glass window manufacturer either purchases tempered glass cut to specified window sizes or purchases window glass and then sizes and tempers the windows as necessary.

Quality assurance is a straightforward problem for annealed glass. It is necessary to detect surface flaws or cracks on the order of 0.060 inch deep which can easily be accomplished using side lighting and unaided vision. For tempered glass, however, surface flaws are often closed by the surface compression produced during the tempering process. In this case, flaws cannot be easily detected without sophisticated test procedures and equipment.

Edge finish is extremely critical since the shaping of windows requires cutting, which can leave serious defects. Generally, edges are ground smooth and radiused to minimize defects. Edges are often subjected to bending and thermal stresses and can become the origin of fractures. A pane of window glass held in an opaque frame can experience a tensile stress of 1000 psi at the edge if solar heating elevates the central portion of the pane by 10 degrees Celsius relative to the edge.

Edge strength can be qualitatively evaluated by covering both sides of a glass panel, except for a small edge band, with heating blankets. The pane is then heated, introducing a uniform tensile stress at the edge which can be monitored by using a polarimeter as temperature and stress rise. The polarimeter indicates the degree of optical retardation of light due to stress in the glass.

For fully tempered glass, with one exception, the existing standards require testing of glass panels using a single point load to test the sample. Using case 2 on page 216 of Formulas of Stress and Strain (reference I6) and the test data from ISO 614 (reference A1), which is common to all standards, Table 9 was developed to determine the

Thickness		Test Load		Stress
mm.	in.	N.	lb.	psi
6	0.235	3400	764.35	21952
8	0.315	6500	1461.26	23607
10	0.394	10200	2293.05	23709
12	0.472	15500	3484.54	25019
15	0.591	24000	5395.41	24793
19	0.748	33400	5708.62	21505

Table 9
Stresses Due to ISO 614 Test Loads

approximate tensile stress to which the samples are tested. In each case, the test load stress is essentially equal to the 20,000 psi breaking stress defined by the glass industry for a 60-second load duration.

While the test pieces are loaded to the breaking (ultimate) stress, the loading configuration is much different than expected in operating conditions. An installed marine window will generally be subjected to a uniformly distributed pressure load over its entire surface rather than over a small portion of its surface, similar to a point load. The difference in loading configurations may cause variations in the test results.

The Japanese Industrial Standards (reference E3) specify three test load conditions. In addition to a single point load similar to that described in ISO 614, an impact test and a uniform pressure test are performed. The impact test consists of dropping a steel ball of specified weight and size onto the test piece from a set height. For the pressure test, the sample is subjected to a uniform hydraulic pressure on one side.

Only the British Standard (reference B2) allows the acceptance of batch lots of glass plates based on the testing of a prescribed number of representative samples (no less than 2 percent of batch population).

While simple load testing to the breaking stress is relatively straightforward for annealed glass, the properties of tempered glass cause significant difficulties. When glass is tempered by rapid cooling after annealing, the surface material contracts immediately. After some time, the inner material cools and contracts, subjecting the outer surfaces to a large compressive force. This surface compression can close existing surface flaws so that they no longer can been seen by conventional inspection methods.

If a tempered glass plate is then subjected to a simple test load, the initial loading may not cause failure but may cause an existing flaw to be propagated through the glass so that the plate will fail at a lower stress in subsequent cycles. Therefore, the inspection and testing requirements contained in the existing window standards cannot be considered "non-destructive" since they may lower the effective strength of the glass.

The British standard (reference B2) requires that each glass be examined in polarized light over its entire surface. While this inspection is supposed to ensure that the glass is "properly toughened", no acceptance criterion is provided. An updated version of this inspection technique, the polarized laser scattered light method, was shown to be a reliable method to assess central plane tension and derive surface compression in tempered glass by Bateson (reference I4). In addition to being a truly non-destructive method of inspection, it is able to determine the uniformity of surface pre-stressing and is applicable to chemically-strengthened glass.

Tempered glass is effectively stronger than annealed glass because its outer surface has been "pre-stressed" by a compressive load. This pre-stress load must be overcome before tensile stresses leading to failure begin to occur. The value of the pre-stress is considered so critical that the Federal Specification DD-G-1403 (reference G1) specifically requires a minimum surface compression of 10,000 psi and edge compression of 9700 psi for fully-tempered glass. The differential surface refractometer, or DSR, invented by PPG Industries and now marketed by Gaertner Scientific, is capable of measuring temper surface compression without damaging the test piece. In order to measure the uniformity of temper, several spots on both major surfaces can be measured and compared. This inspection method is also applicable for chemically-strengthened glass.

CONCLUSIONS

While a considerable number of different specifications and standards are available for the design of marine windows, they share a mutual relationship in the developmental work performed in the late 1960's prior to the initial release of the series of ISO standards for ship's windows and scuttles. This work was based on the superstructure/deckhouse structural criteria developed by the International Association of Classification Societies (IACS). As a result, the existing standards each attempt to yield a glass window equivalent in strength to that of the structure in which they are installed.

Although a significant amount of analytical research has been performed on the loads produced by the marine environment to which ships' structure is subjected, only a limited number of modifications have been made to the structural design criteria to incorporate this theoretical work.

In simpler terms, while research has been and is being performed in the area of the determination of wind and sea loads on ship superstructure or deckhouses, the current revision of the structural criteria developed by IACS remains the most consistent and proven means for designing adequate structures. The efforts to expand the understanding of the marine environment and its effects on ship structures in order to obtain further refinements to the existing standards need to remain a priority.

The existing marine window standards require that all window or scuttle glass be fully tempered and are based on general mechanical properties for tempered glass dating from the early 1960's. More recent research and experience has indicated that some of the basic assumptions made during the development of the existing standards must be revised before they can be applied for much larger windows.

As illustrated by the calculation performed earlier, the existing window standards are based on a working stress for fully tempered glass of approximately 6000 psi while current glass industry practice, as noted by E.B. Shand in reference I7, dictates an upper limit of 4000 psi on working stress for very large glass items. The primary reasons for this reduction in allowable strength are the greater probability of handling damage due to larger exposed surfaces or the presence of significant surface flaws from the manufacturing process for larger glass products.

Our research revealed no trends towards the failure of windows designed to the existing standards, even though the allowable working stress used as a basis of the applicable design criteria (6000 psi) is higher than currently recommended by the glass industry (4000 psi). Therefore, it appears that the design loads required by existing standards are more severe than the actual loads encountered in service. However, if a

more accurate or rigorous analysis of design loads for large windows is used by the designer, then the glass industry recommended allowable stress level of 4000 psi should be used for determining glass thickness.

On a practical side, as a part of the review of the existing marine window standards, an evaluation was made concerning the ease with which each of the documents could be used and to identify areas which could be easily misunderstood, resulting in erroneous findings. It is our opinion that the British Standards (references B1 and B2) were written in the most straightforward manner when compared with all of the documents in use. In a large part, this was due to the fact that all the requirements concerning the design and installation of marine windows were combined in a single, well-organized document. Most of the other regulatory bodies followed ISO's lead and issued a number of related documents, each covering a portion of the technical requirements with areas of overlap, repetition, and a number of instances of apparently contradictory information. In general, glass standards for marine windows should be developed and issued in one concise publication.

While a number of studies have been performed documenting the apparent effects of service life on the strength of glass they have tended to simply report the results of testing indicating that glass strength decreases with age. Very few rigorous evaluations have been made to determine the reason for the decrease in glass strength. There are some indications, however, that flaw size and number, the critical element in glass failure, may increase with age. Thus, mechanical and thermal cycling, which act as mechanisms to propagate existing flaws, effectively lower glass strength. Similarly water, as a polar liquid, is a corrosive agent to enlarge surface flaws, which may round out flaw tips and increase glass strength. No definitive research was found on the effects of chemical or ultraviolet light exposure on the mechanical properties of glass.

Of major concern must be the adequacy of the existing testing procedures. The load testing required by the existing standards is very limited in scope and generally does not utilize loading conditions similar to those expected in service. In addition, due to the physical properties of glass, while load tests may demonstrate that the glass test piece is structurally adequate to resist the minimum breaking stress for the initial load, the action of applying a concentrated load may cause existing surface flaws to be propagated. Consequently, the test piece may fail at a lower subsequent load than originally tested due to the increase in possible stress concentrations caused by the enlarged flaws from initial testing. It is possible to pressure test windows non-destructively by lowering the stress temperature with liquid nitrogen to eliminate static fatigue, but this testing is slow and expensive (space shuttle windows are tested in this manner).

A number of non-destructive test methods, such as polarized laser scatter light method and the Differential Surface Refractometer (DSR), have been studied and have demonstrated their ability to measure compression introduced by the tempering process

and to ensure the adequacy of a glass plate. Ultrasonic surface wave testing has been proposed for the detection and size determination of surface flaws after tempering. This non-destructive testing method may prove effective in detecting surface flaws. However, the determination of proper technique and limiting factors in flaw detection has not been perfected. The combination of a high-frequency transducer/receiver and a microcomputer with high resolution imaging software holds tremendous promise for detection of surface defects. Glass panels could be ultrasonically scanned and a permanent record of the surface condition could be made of the "picture" produced by the high-speed interpretation of the transducer output produced by the microcomputer. While the basic technology to scan and record the surface condition of a glass panel is technically feasible, further research and testing is necessary to determine the best scanning method and combination of equipment components necessary to accurately determine defect size (depth). In addition, an acceptance criteria must be developed to clearly identify the maximum allowable defect depth. Potentially, it may be possible to utilize ultrasonic surface wave testing to produce a high-resolution map of a glass panel identifying each surface defect and its depth while evaluating the acceptability of the panel. The development of the above-mentioned testing procedure and criteria could be the subject of a separate research study.

At present, testing in accordance with the existing standards (ISO and national standards) is the responsibility of the window manufacturer. The regulatory body confirms that the glass window has documentation indicating that the window manufacturer has tested the window. Regulatory bodies, responsible for the acceptance of marine windows, should establish methods for certifying and periodically auditing manufacturers' testing programs to ensure that they comply with the requirements of the standards.

As stated in the introduction to this report, one major goal of this study was to determine whether the methods and criteria in the existing standards can be applied to large windows of the size currently envisioned by designers. While somewhat conservative, the method for calculating the design pressure or load for a window is valid regardless of window size. Since this method is identical to the design criteria for deckhouse structure used by all the major classification societies, the result will be windows with strength comparable to the structure in which they are installed.

Based on the results of recent research, however, it appears that the allowable working stress should be reduced for large windows since glass failure load has been found to decrease as glass area increases. It may be reasonable, however, to continue to use 6000 psi as the allowable working stress for standard marine windows since there is no data indicating significant numbers of window failures. For large windows with accurate methods of load prediction, it is recommended that the allowable working stress be reduced to 4000 psi for long-term use of tempered glass.

Aside from the problem of exactly evaluating the tensile stresses at surfaces, the quality of the glass surface is difficult to assess and its change with time and use impossible to predict, in most cases. Glass handling treatment during installation or construction/repair operations has been the cause of many glass failures. For these reasons, a conservative approach is recommended with the following limits corresponding to current glass industry practice:

Annealed glass, long term:	1000 psi
Annealed glass, short term:	2000 psi
Tempered glass, long term:	4000 psi
Tempered glass, short term:	5000 psi

Further research should be performed on tempered glass samples of various sizes to quantitatively define the relationship between glass area and failure load.

As briefly noted in the body of this report, information on chemically-strengthened glass is extremely limited. It would appear that developments in this area have been limited to the laboratory; very little data is available on in-service performance of chemically-strengthened glass. This material, however, does hold promise for use as windows in areas of high loading and stresses since recommended allowable working stresses on the order of 16,000 psi are possible. Additional studies will be necessary of the various types of chemically-strengthened glass available, their compatibility with the marine environment, and maximum allowable working stresses.

Since surface defects play a critical role in glass failure, as another area of continuing study, surface coatings should be researched and tested, if possible, to determine if it is possible to reduce the size and frequency of chips or scratches. This could lessen the decrease of window strength due to age. This is a very challenging problem for research since the optical properties must be retained with time as well. The combination of surface coatings with chemical strengthening should also be studied to determine the possibility of creating "high strength" glass for highly-loaded windows.

RECOMMENDATIONS

As a result of the investigations of existing marine window standards as well as documentation on research into glass strength and loads on structures due to the marine environment, the following recommendations were reached concerning technical requirements for the design and manufacture of marine windows:

1. A standard for the design, manufacturing, testing, and installation of marine windows should be developed and issued in a single, concise publication. This will minimize the chances of confusion, misinterpretations, and contradictory requirements.

   As a member of the ISO Committee, the U.S. Coast Guard should consider proposing that the existing ISO standards be combined into a single, concise document.

2. The 6000 psi allowable stress used as a basis for the design of the "standard" size windows presented in the existing design standards should be maintained when utilizing the current procedure for determining design loads (IACS Unified Requirement S3).

3. For windows larger than those described in the existing standards or where a more rigorous analysis of design loads is used, an allowable stress level of 4000 psi should be utilized for determining the minimum requirements for glass thickness.

4. Rather than using the current point load testing technique, which can propagate existing surface flaws in tempered glass and decrease its strength, non-destructive test methods should be utilized to verify the structural adequacy of tempered glass panels under more realistic loading conditions.

5. A method for certifying and periodically auditing the manufacturers' production and testing programs should be developed to ensure that all the requirements of the applicable standards are complied with.

6. A coordinated research program should be created to provide guidance to scientists, engineers, and technicians so that research efforts will yield more practically oriented data. As a minimum, future research should be performed in several key areas:

a. Basic research into the nature of the marine environment with emphasis on loads to which ship structure is subjected due to the combined effects of wind pressure and wave impact.

b. Non-destructive test methods for determining the adequacy of glass panels should be developed. Emphasis should be placed on methods of detecting and measuring surface defects on tempered glass, such as Ultrasonic Surface Wave testing, since breaking pressure has been determined to be a function of defect size.

c. Testing of tempered glass samples of various sizes should be performed to support the development of a quantitative relationship between glass area, thickness, and failure load. If possible, direct strain measurements should be taken during this testing to confirm the predicted stress levels in the glass.

e. The use of surface coatings, which would make glass panels more resistant to surface damage and the resultant degradation of panel strength.

f. The use of chemically-strengthened glass for marine windows.

Additionally, it is recommended that consideration be given to the periodic examination of existing marine windows located in critical locations. This visual examination, in accordance with established acceptance criteria, may be supplemented by more sophisticated testing equipment when available.

BIBLIOGRAPHY

A. International Standards Organization (ISO)

1. ISO 614 "Shipbuilding--Toughened Safety Glass Panes for Ships' Side Scuttles and Ships' Rectangular Windows--Punch Method of Non-Destructive Strength Testing", 1976.

2. ISO 1095 "Shipbuilding--Toughened safety glass panes for ships' side scuttles", 1976

3. ISO 3254 "Shipbuilding--Toughened Safety Glass Panes for Ships' Rectangular Windows", 1975.

4. ISO 3903 "Shipbuilding--Ships' Ordinary Rectangular Windows", 1977.

5. ISO 5779 "Shipbuilding--Ordinary Rectangular Windows--Positioning", 1987.

B. British Standards Institution

1. BS MA 24 "Ships' Side Scuttles", October, 1974.

2. BS MA 25 "Ships' Windows", October, 1973.

C. Swedish Standards Commission (SIS)

1. Proposed SVENSK Standard SS 78-02-67 "Shipbuilding--Windows on Ships--Summary and Installation".

2. Proposed SVENSK Standard SS 78-20-XX "Shipbuilding--Windows on Cargo Ships--Positioning".

3. Proposed SVENSK Standard SS 78-08-27 "Shipbuilding--Toughened Safety Glass Panes for Ships' Rectangular Windows".

4. Proposed SVENSK Standard SS-ISO)-614 "Shipbuilding--Toughened Safety Glass Panes for Ships' Side Scuttles and Ships' Rectangular Windows--Punch Method of Non-Destructive Strength Testing".

D. Norwegian Industrial Standards Institute (NVS)

1. NS 6149 "Shipbuilding--Ships' Ordinary Rectangular Windows", 1980.

2. NS 6150 "Shipbuilding--Toughened Safety Glass Panes for Ships' Rectangular Windows", 1980.

3. NS 6153 "Marine Industry--Ships' Side Scuttles and Ordinary Rectangular Windows", 1983.

E. Japanese Industrial Standards (JIS)

1. JIS F2402 "Ships' Hinged Rectangular Windows", 1979.

2. JIS F3206 "Tempered Glass"

3. JIS F2410 "Toughened Glasses for Ships' Side Scuttles", 1978.

F. Italian Register of Naval Architects (RINA)

1. Registro Italiano Rules Section 20.10 "Side Scuttles and Windows", 1975.

2. UNAV 4925-4928 Italian Standards for Windows

G. U.S. Federal Specifications and Military Standards

1. New Interim Federal Specification DD-G-001403 "Glass, Plate (Float), Sheet, Figured and Spandrel (Heat Strengthened and Fully Tempered)", August, 1971.

2. Federal Specification DD-G-451C "Glass, Plate, Sheet, Figured (Float, Flat, For Glazing, Corrugated, Mirrors, and Other Uses)", January 15, 1968.

3. MIL-G-2857A "Glass, Heat Treated, Glazing, Rectangular (for Bridge Windows)", 28 June 1968.

4. MIL-G-3787G "Glass, Laminated, Flat (Except Aircraft)", 20 September 1976.

H. Industry Guidelines

1. PPG Industries Technical Service Report No. 101 "Glass Product Recommendations--Structural"

I. Independent Research Reports and Books

1. "The Strength of Weathered Window Glass Using Surface Characteristics", Jean Jamil Abiassi, Glass Research and Testing Laboratory, Texas Tech University, August, 1981.

2. "The Strength of New Window Glass Plates Using Surface Characteristics", Diboro C. Kanabolo and H. Scott Norville, Glass Research and Testing Laboratory, Texas Tech University, July, 1985.

3. "Changes in the Tensile Strength of Glass Caused by Water Immersion Treatment", G.F. Stockdale, F.V. Tooley, and C.W. Ting, Journal of the American Ceramics Society, Volume 34(4), pgs. 116-121.

4. "Stress Measurements in Tempered Glass Plates by Scattered Light Method With a Laser Source", S. Bateson, J.W. Hunt, D.A. Dalby, and N.K. Sinha, American Ceramic Society Bulletin Volume 45(2), pgs. 193-198, 1966.

5. Handbook of Ocean and Underwater Engineering, Edited by J.J. Myers, C.H. Holm, and R.F. McAllister, McGraw-Hill Co., 1969.

6. Formulas for Stress and Strain, 4th Edition, Raymond J. Roarke, McGraw-Hill Co., 1965.

7. Glass Engineering Handbook, 3rd Edition, G.W. McCellan & E.B. Shand, McGraw-Hill Co., 1984.

8. Ocean Engineering Structures, J. Harry Evans and John C. Adamchak, The M.I.T. Press, 1969.

9. "Design Strength of a Chemically Strengthened Glass", Henry E. Hagy, Central Glass and Ceramic Research Institute Bulletin, Vol. 13, No. 1, 1966, pgs. 26-31.

10. "Damage Due to Shipping Green Water and Design Standard", 5th ISCC Committee Report, No. 8, September, 1973.

11. "Stochastic Prediction of Impact Pressure Due to Shipping Green Sea on Fore Deck of Large Ore Carrier Ship", Masuo Kawakami and Kazumasa Tanaka, Transactions of J.S.N.A., Japan, No. 53, March, 1977.

12. "Breaking Waves--The Plunging Jet and Interior Flow Field", E.D. Cokelet.

13. "On the Impact Strength of Ship Due to Shipping Green Seas", Masuo Kawakami, Transactions of J.S.N.A., Japan, Vol. 125, June, 1969, Towing Experiments of a Ship Model in Regular Waves.

14. Rules for Building and Classing Steel Vessels, American Bureau of Shipping, 1988 Edition.